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OF PILOTS AT GREAT ALTITUDES

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by

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The effect of high altitudes on the ocular refraction of pilots was studied in altitude chambers, by means of proximeters. Transient myopia of a degree proportional to the altitude, is produced by spasm of the ciliary muscle. Astigmatism, myopia, and other refraction anomalies are intensified at great altitudes, leading to pilot fatigue. Persons with slight hypermetropia (+1, +2 diopt.) are less affected.

Authos

Under the conditions of flight at high altitudes, the pilot must have normal visual acuity to be adaptable to these working conditions.

Ocular refraction is the most important parameter for achievement of visual acuity.

By state of ocular refraction are meant the deviations, produced in a light ray penetrating the eye, by the refringent surfaces and centers of the visual analyzer, as well as the position of the retina with respect to the cornea and crystalline lens. This refraction is static if the curvatures of the

* Numbers in the margin indicate pagination in the original foreign text.

crystalline lens remain stable or dynamic if the curvatures, i.e., the refringence of the crystalline humor, change under the influence of accommodation.

The prime factors of ocular accommodation are the modifications of the curvature of the facets of the lens, which change the refraction and permit the formation of light-ray foci on the retina, no matter where they originate.

Many researchers mention frequent modifications in refraction, as part of the ocular deficiencies responsible for local or general disorders (Bibl.6,19).

All symptoms that accompany modifications of the ocular refraction become aggravated during the working process, leading to fatigue phenomena.

Another point to be considered is the influence of ambient factors on the visual analyzer, specifically if disorders of refraction are involved (hypermetropia, myopia, astigmatism) which are not adaptable and lead to signs of fatigue (Bibl.3, 4, 5, 15, 16, 17).

p.2

The hypobarism at great altitudes determines the functional modifications at the level of the optical analyzer, particularly of the ocular refraction.

In our research, we studied the ocular refraction jointly with the visual accommodation under the reduced-pressure conditions of the altitude chamber, equivalent to flight at great altitudes.

Experimental Conditions

A total of 12 ocular parameters were investigated, in order to establish the functional capacity of the visual analyzer of pilots.

We present here only the results obtained for two parameters - refraction and visual accommodation - with 382 pilots, divided into four groups which were subjected to altitude-chamber tests at 5000, 12,000, 15,000 and 18,000 m.

The ocular refraction was determined by means of a coincidence refractometer (Hartinger) under normal conditions, at ground level, at rest, and im-

mediately after leaving the altitude chamber.

Together with the ocular refraction, the visual accommodation was stud-

ied, specifically the proximetry, by means of an electric monocular proximeter (M. Popesco).

This instrument permitted a study of the "punctum proximum", even during the tests in the altitude chamber, at various moments of the test series. The results were transmitted over an electric cable to outside of the altitude chamber, which permitted a determination of the dynam-

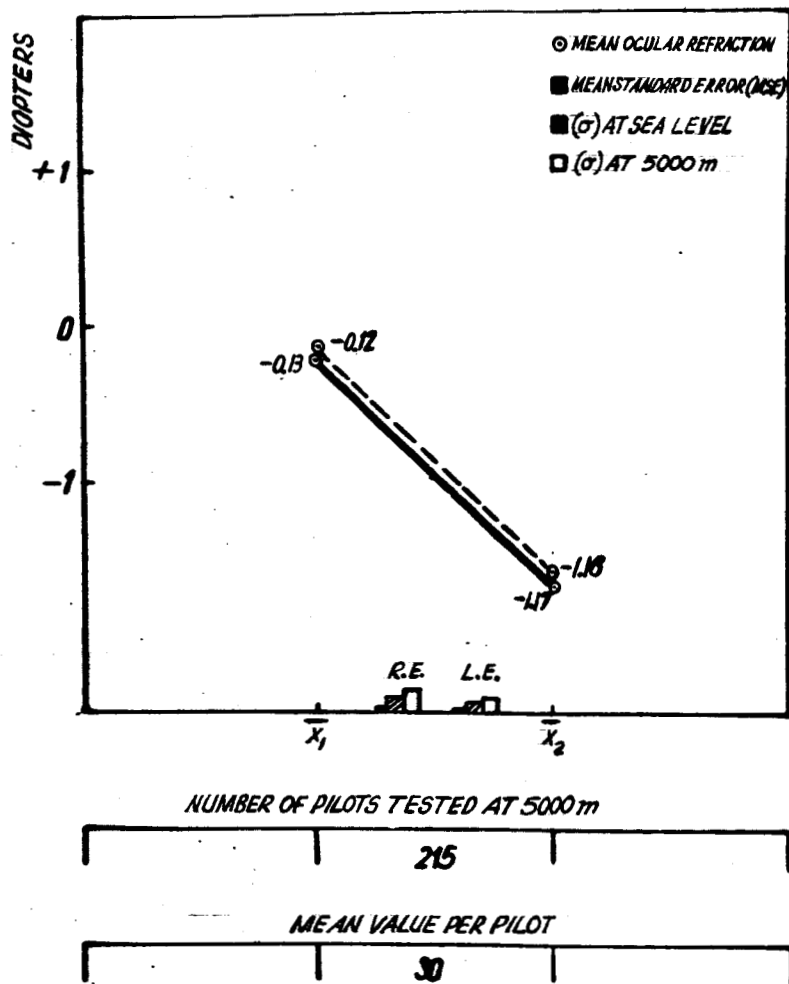


Fig.1 - Mean Values of Ocular Refraction, in Diopters ($\bar{x}$) of Pilots of Group No.1, at Sea Level, at Rest ($\bar{x}_1$), and Immediately after the Low-Pressure Test at 5000 m ($\bar{x}_2$), for the right eye (-) and for the left eye (—)

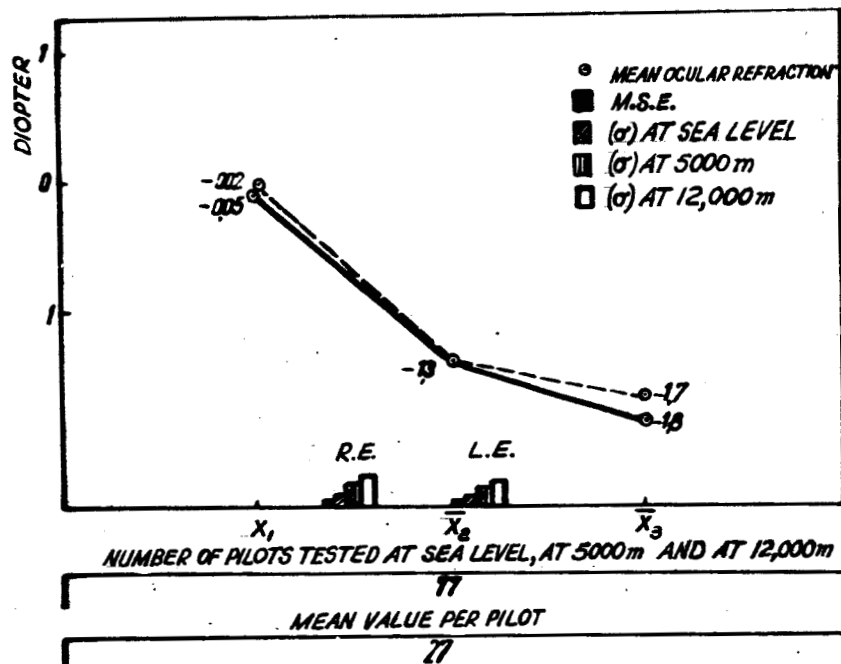
ics of visual accommodation.

We analyzed the normalization of ocular refraction and of the punctum proximum at sea level, after termination of the altitude-chamber test, every ten minutes over the period of one hour.

Experimental Results

p.3

The ocular refraction showed an increase in all pilots of the four groups, manifesting itself by a myopia proportional to the altitude, for both



eyes, with the following mean values: at 5000 m, 1.04 $\pm$ 0.02 diop-
ters; at 12,000 m, 1.21 $\pm$ 0.06 diop-
ters; at 15,000 m, 1.60 $\pm$ 0.06 diop-
ters; at 18,000 m, 1.65 $\pm$ 0.09 diop-
ters.

Fig.2 - Mean Values of Ocular Refraction, in Diopters ($\bar{x}$) for Pilots of Group No. II, at Sea Level (at Rest) ($\bar{x}_1$) and Immediately after the Altitude-Chamber Test at 5000 m ($\bar{x}_2$) and at 12,000 m ($\bar{x}_3$), for the right eye (-) and for the left eye (—)

A statistical analysis of the data obtained for each group resulted in a high variability factor, because of the fact that the refraction in these subjects was not homogeneous.

The ocular refraction at sea level, at rest, showed in a small number of the pilots, a negligible myopia or hypermetropia. Table 1 contains the statistical values of the ocular refraction for the group No.1 (5000 m).

A comparison of the mean values, obtained upon leaving the altitude chamber (5000 m, 12,000 m, 15,000 m, and 18,000 m) with those obtained at sea

Table 1

Mean Values for the Ocular Refraction ($\bar{x}$) in Diopters, the Standard Errors (S.E.) and the Variability Coefficient (V.C.) for Pilots at Sea Level, at Rest ($\bar{x}_1$) and Immediately after the Altitude-Chamber Test at 5000 m ($\bar{x}_2$) for the Left Eye (L.E.) and for the Right Eye (R.E.) The Values of t and p for the Differences between the Mean Values of the Ocular Refraction at 5000 m and the Mean Values obtained at Sea Level for R.E. and L.E. (Group No.I)

R.E.				L.E.			t		p
	$\bar{x}$ Diopt.	S.E.	V.C.	$\bar{x}$ Diopt.	S.E.	V.C.	R.E.	L.E.	AO
x_1	-0,13	$\pm 0,03$	38	-0,12	$\pm 0,02$	36	24	25	< 0,001
x_2	-1,17	$\pm 0,07$	55	-1,16	$\pm 0,03$	43			

level (differences for the four groups), indicates a very significant increase of the refringence of the crystalline lens, with appearance of low-pressure myopia $p < 0.001$.

To check on the modification of ocular refraction under the reduced-pressure conditions at great altitudes, we studied the dynamic visual accommodation of the punctum proximum during the tests in the altitude chamber.

These studies confirmed the results obtained on ocular refraction: In fact, the punctum proximum is more closely approached than that recorded at sea level, at rest, before the decompression, i.e., an increase in the amplitude of accommodative contraction. This approach of the punctum proximum appears about 15-20 minutes after the beginning of the pressure drop and dimin-

ishes progressively, relative to the altitude, until the end of the test.

p.4

The punctum proximum showed a decrease for both eyes, with a mean of 1.5 ± 0.01 cm for Group No.I (5000 m); 2.5 cm for Group No.II (12,000 m); 2.90 ± 0.18 cm for Group No.III (15,000 m), and 2.95 ± 0.27 cm for Group No.IV (18,000 m).

To give an example, we will present the statistical data of Group No.IV (18,000 m).

Table 2

Mean Values of the Punctum Proximum ($\bar{x}$), in Centimeters, the Standard Errors (S.E.) and the Variability Coefficient (V.C.) for the Pilots, at Sea Level, at Rest ($\bar{x}_1$) and in the Altitude Chamber at 5000 m ($\bar{x}_2$), at 12,000 m ($\bar{x}_3$), at 14,000 m ($\bar{x}_4$), at 16,000 m ($\bar{x}_5$), and at 18,000 m ($\bar{x}_6$) for the Right Eye and the Left Eye. The values of t and p are for the differences between the mean values of the punctum proximum at 5000 m ($\bar{x}_2$), at 12,000 m ($\bar{x}_3$), at 14,000 m ($\bar{x}_4$), at 16,000 m ($\bar{x}_5$), at 18,000 m ($\bar{x}_6$) and the values obtained at sea level ($\bar{x}_1$) for R.E. and L.E. (Group No.IV)

			R.E.			L.E.			t	p
$\bar{x}$ cm	S.E.	V.C.	$\bar{x}$ cm	S.E.	V.C.	$\bar{x}$ cm	S.E.	V.C.	R.E.	L.E.
x_1 9.6	± 0.30	15	9.6	± 0.30	15				-	-
x_2 8	± 0.31	19	8	± 0.37	22	$\bar{x}_2 - \bar{x}_1$	6	4	0.001	
x_3 7.7	± 0.32	21	7.6	± 0.36	23	$\bar{x}_3 - \bar{x}_1$	6	5	0.001	
x_4 7.4	± 0.36	24	7.6	± 0.18	12	$\bar{x}_4 - \bar{x}_1$	7	4	0.001	
x_5 7	± 0.20	15	7	± 0.20	14	$\bar{x}_5 - \bar{x}_1$	8	7	0.001	
x_6 6.6	± 0.20	16	6.7	± 0.23	15	$\bar{x}_6 - \bar{x}_1$	10	7	0.001	

Interpretation of the Results

The functional modifications of the visual analyzer at reduced pressure

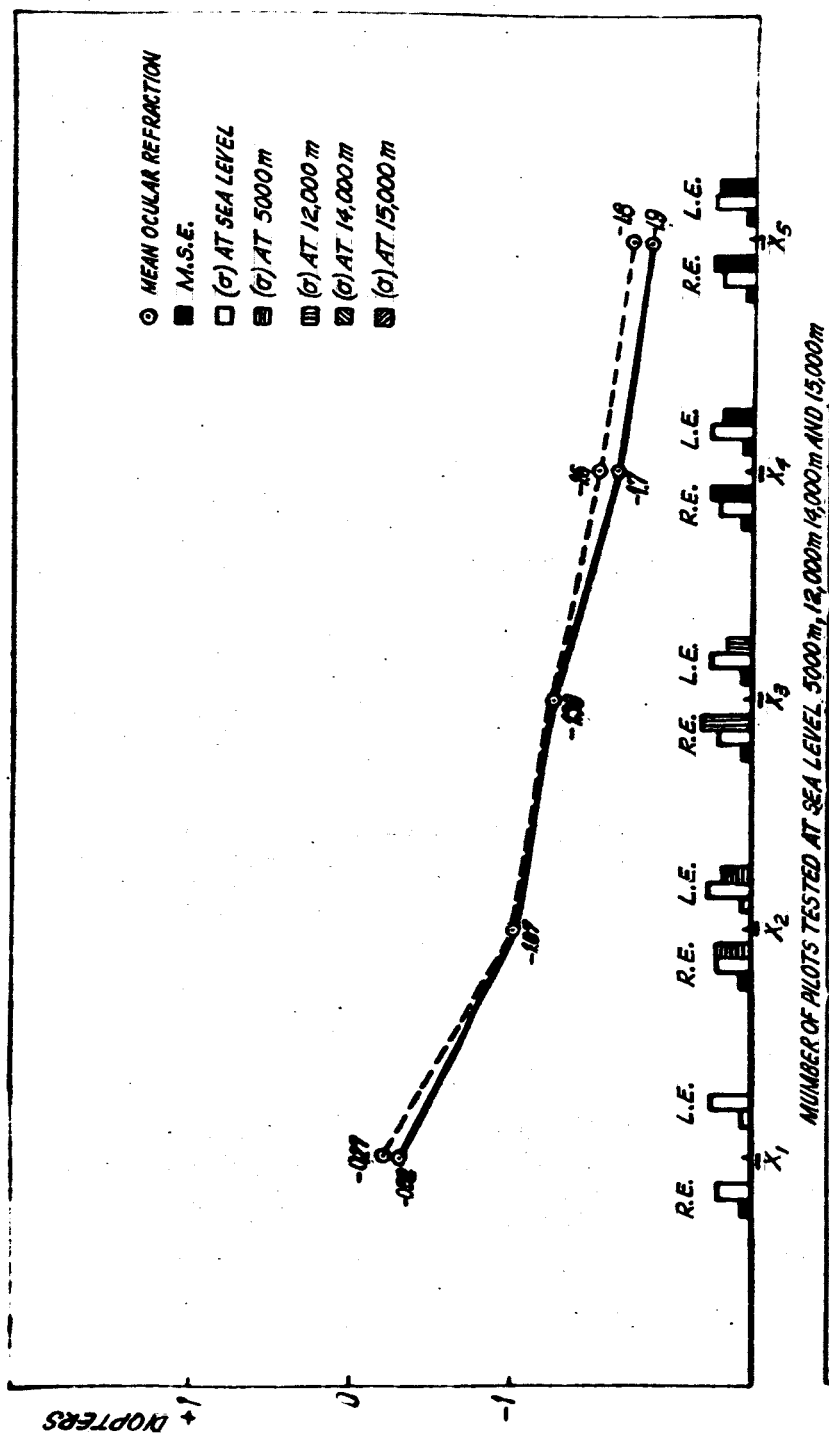


Fig.3 - Mean Values of the Ocular Refraction, in Diopters for the Pilots of Group No. III at Sea Level, at Rest ($\bar{x}_1$), and Immediately after the Altitude-Chamber Test at 5000 m ($\bar{x}_2$), at 12,000 m ($\bar{x}_3$), at 14,000 m ($\bar{x}_4$), at 15,000 m ($\bar{x}_5$) for R.E. (—) and L.E. (---)

are mostly produced by reflex mechanisms which enter the hypoxic disorders of the higher nervous activity (Bibl.1, 2, 7, 8, 14). The hypoxia has a specific

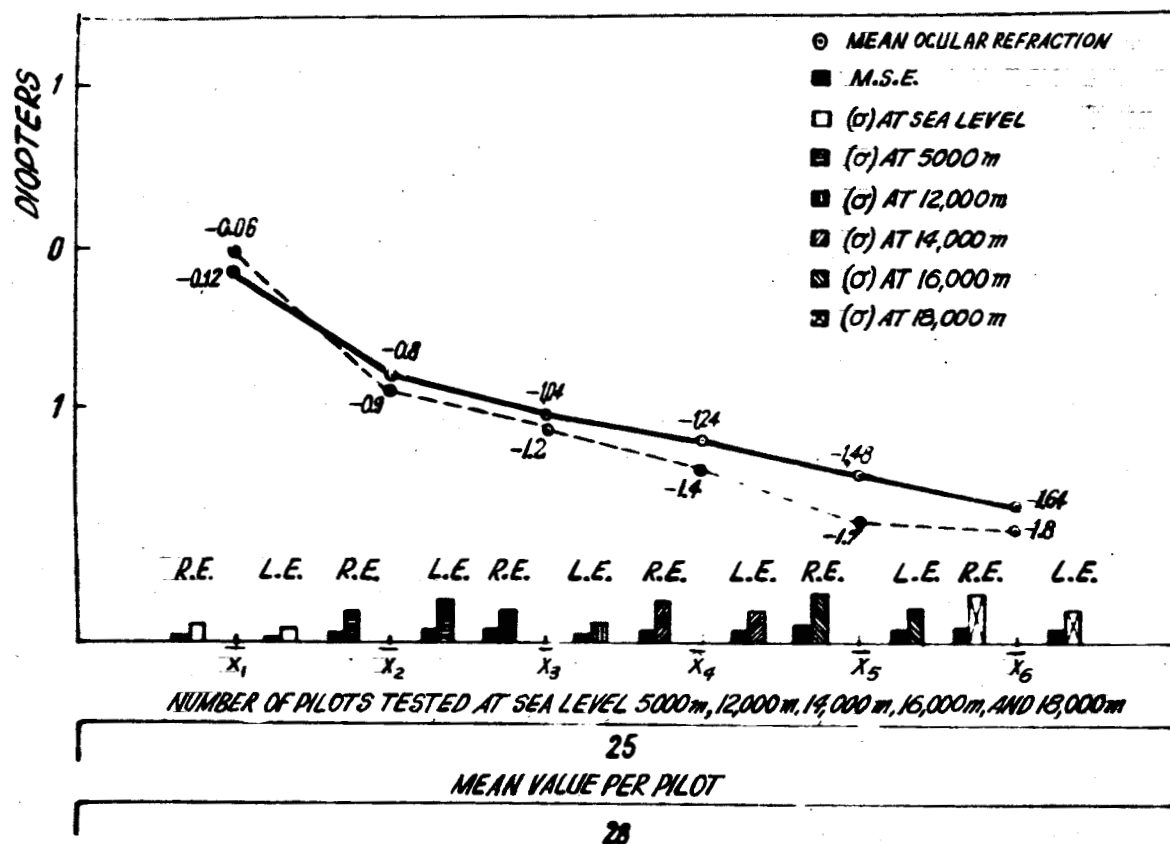


Fig.4 - Mean Values of Ocular Refraction in Diopters ($\bar{x}$) for the Pilots of Group No. IV, at Sea Level, at Rest ($\bar{x}_1$) and Immediately after the Altitude-Chamber Test at 5000 m ($\bar{x}_2$), at 12,000 m ($\bar{x}_3$), at 14,000 m ($\bar{x}_4$), at 15,000 m ($\bar{x}_5$) and at 18,000 m ($\bar{x}_6$) for R.E. (-) and L.E. (--)

influence on the entire organism, also producing functional insufficiencies of certain organs.

Hypoxia primarily influences the smooth musculature and produces there, in addition to severe perturbations of all organs and systems, degenerative modifications.

The ciliary muscle is a smooth muscle; consequently, the appearance of an

increased contraction under the conditions of low-pressure hypoxia is readily explainable.

In the initial compensated phase, when the oxygen of the blood diminishes, hypoxia does not produce distinct disorders in the activity of the nervous

system and leads merely simple to a intensification of the excitation process at the level of the cerebral cortex.

A prolonged oxygen deficiency results in an accumulation of catabolites, leading to a weakening of the principal nervous process due to an inhibition of the protection in the cortex and in the subcortex.

In the altitude-chamber tests, made at 5000 and 18,000 m, the percentage of hypoxia

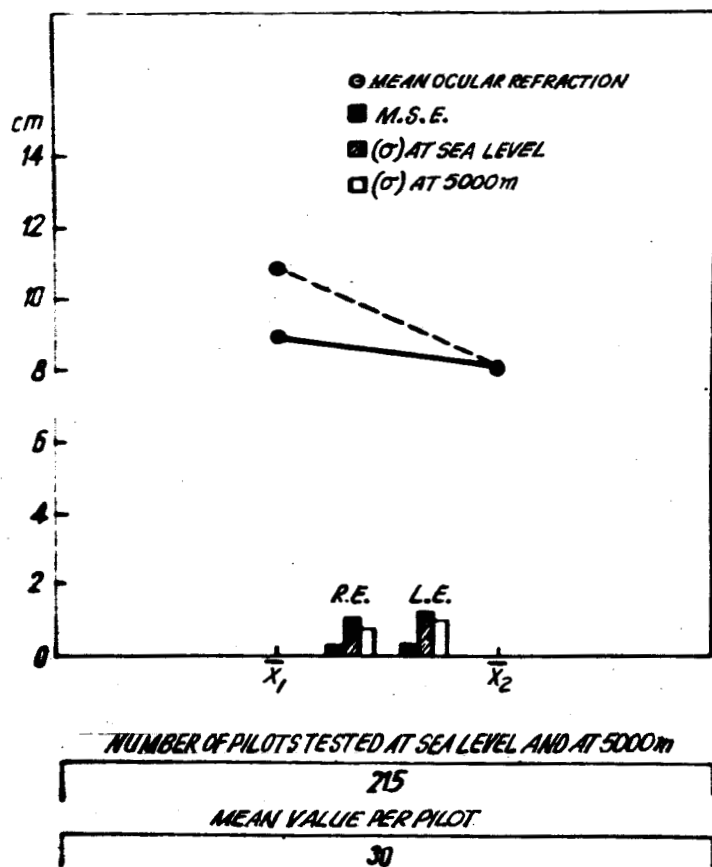


Fig.5 - Mean Values of the Punctum Proximum ($\bar{x}$), in Centimeters, for the Pilots at Sea Level, at Rest ($\bar{x}_1$), and in the Altitude Chamber at 5000 m ($\bar{x}_2$) for R.E. (-) and L.E. (--) Group I

was less because of the fact that, above 5000 m, the pilots breathed oxygen through a special mask. This slight hypoxia resulted in an intensification of the excitation process of the nervous centers, which might explain the appearance of low-pressure myopia by a spasm of the ciliary muscle. In addition to

this chemical component, represented by the hypoxia, the physico-mechanical component must also be taken into consideration. This component is produced by the rarefaction (expansion) of the free gases in the organism. In addition

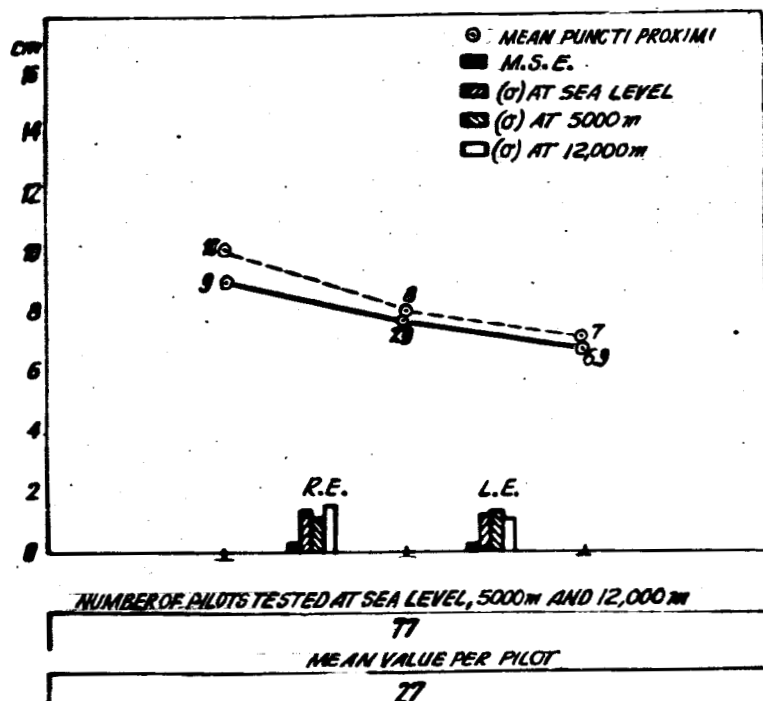


Fig.6 - Mean Values of the Punctum Proximum ($\bar{x}$) in Centimeters, for the Pilots at Sea Level, at Rest ($\bar{x}_1$) and in the Altitude Chamber at 5000 m ($\bar{x}_2$) and at 12,000 m ($\bar{x}_3$) for R.E. (-) and L.E. (—) Group II

times greater in fats than in water.

In the orbit, the ocular globe is surrounded by rich adipose tissue which protects the neurovascular formations. These formations, located in the orbit, also include the ciliary ganglion through which pass the most important nerve tracks (short ciliaries, long ciliaries, and sympathetic fibers) which lead to the ciliary body itself. The relatively large amount of nitrogen which, dissolved in the adipose orbital tissue, produces modifications in the nerve transmission, behaves completely like a foreign body.

to CO_2 and O_2 , dissolved in the blood and in the humors, and possibly completely linked to the hemoglobin and to bicarbonates which are not toxic, there is also nitrogen which is difficult to diffuse. Nitrogen is dissolved in the humors and in the adipose tissues, having a solubility five

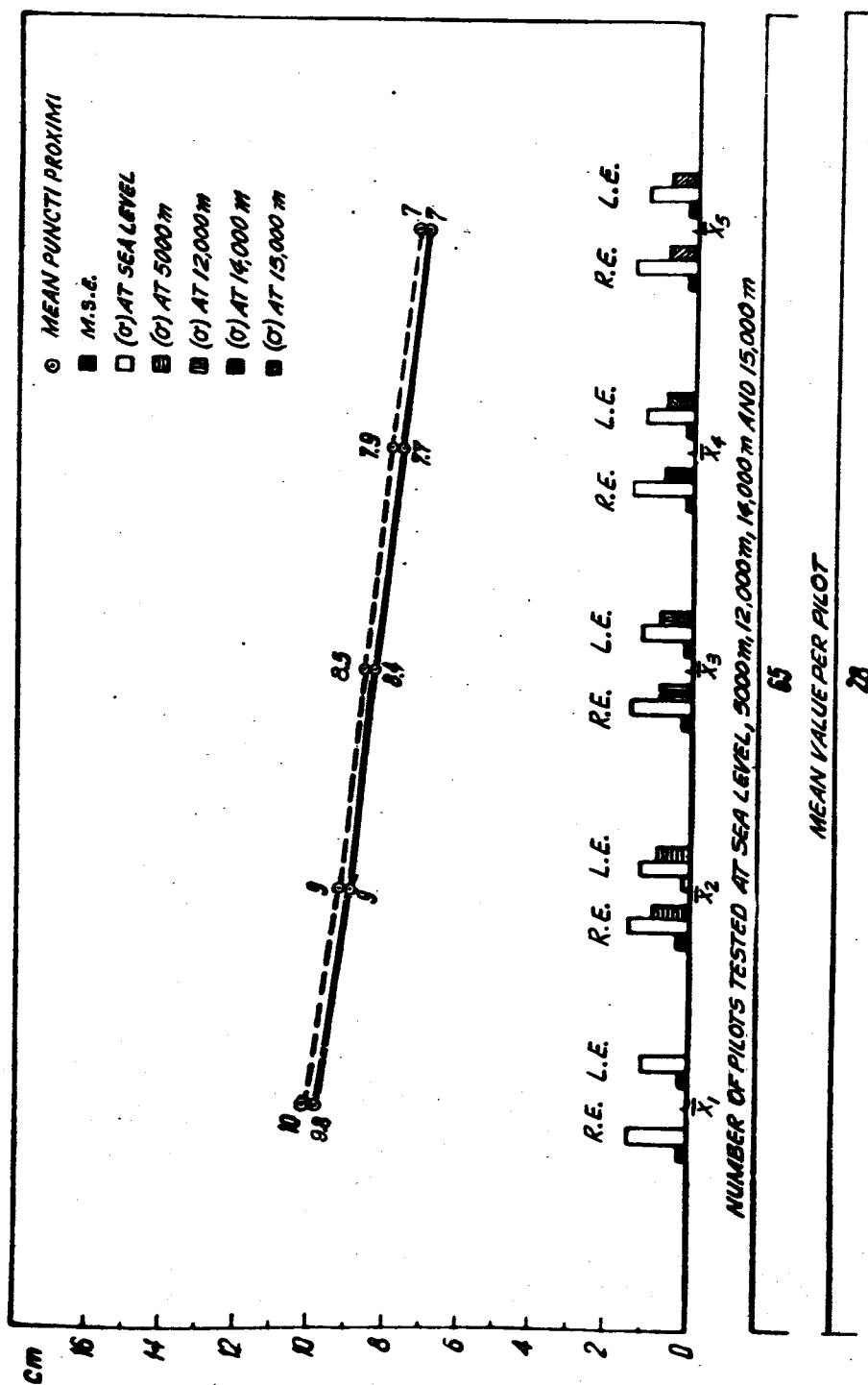


Fig. 7 - Mean Values of the Punctum Proximum ($\bar{x}$), in Centimeters, for the Pilots at Sea Level, at Rest ($\bar{x}_1$), and in the Altitude Chamber at 5000 m ($\bar{x}_2$), at 12,000 m ($\bar{x}_3$), at 14,000 m ($\bar{x}_4$), and at 15,000 m ($\bar{x}_5$) for R.E. (-) and L.E. (---) (Group No. III)

The nitrogen, whose partial pressure is modified, also influences the visual accommodation playing a role in the repolarization phenomena which occur

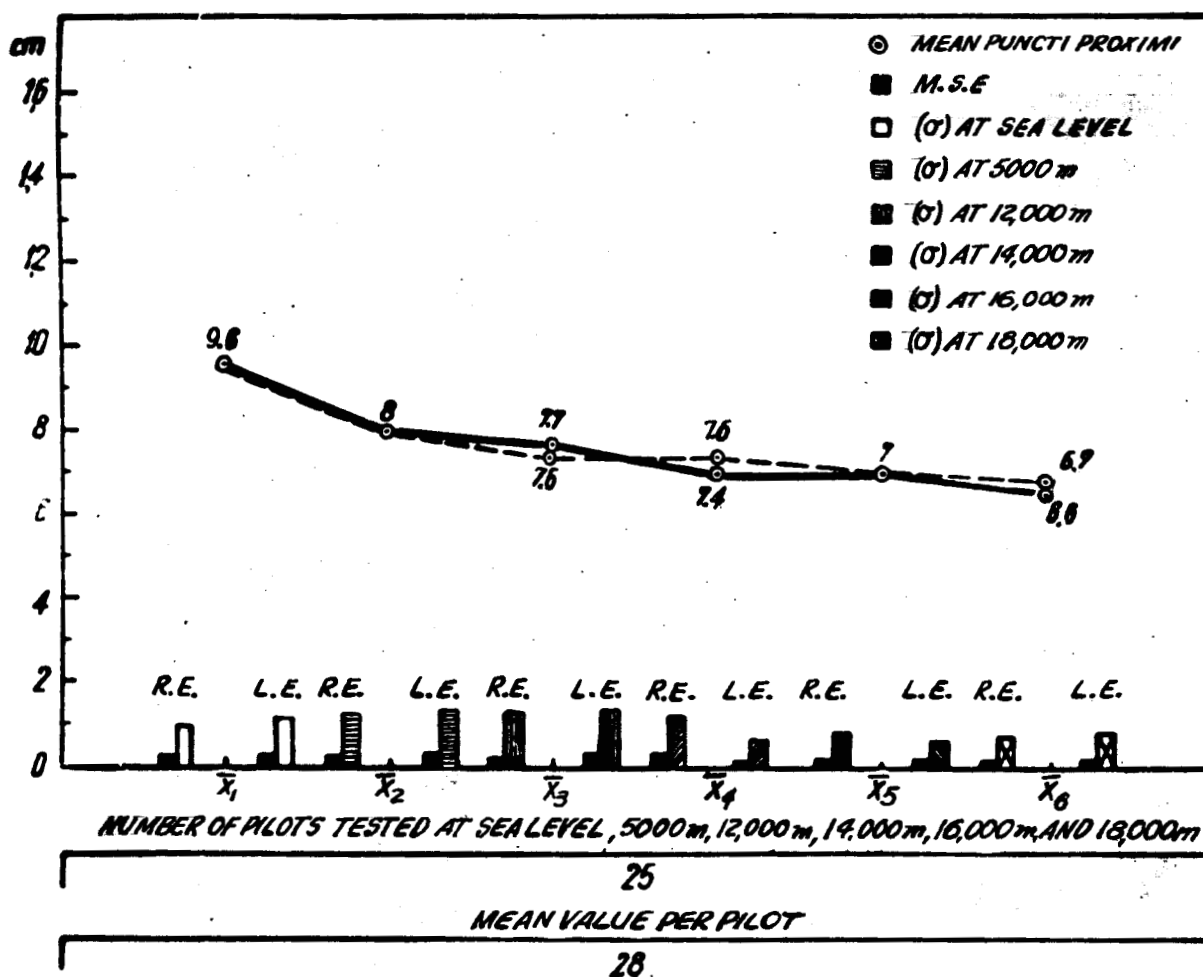


Fig.8 - Mean Values of the Punctum Proximum ($\bar{x}$), in Centimeters, for the Pilots, at Sea Level ($\bar{x}_1$) and in the Altitude Chamber at 5000 m ($\bar{x}_2$), at 12,000 m ($\bar{x}_3$), at 14,000 m ($\bar{x}_4$), at 16,000 m ($\bar{x}_5$), and at 18,000 m ($\bar{x}_6$) for R.E. (-) and L.E. (—) (Group No. IV)

at the level of the ciliary ganglion. At the moment of return to sea level, at normal pressure, a desaturation of nitrogen in the various parts of the analyzer takes place and a normalization of the visual functions occurs.

The visual accommodation of the mobile punctum proximum requiring the adjustment of its dynamic image which oscillates between sharp vision, close

p.6



Fig.9 - Edema at the Base of the Ciliary Body

vision and closest vision, is changed by the reduced pressure at great altitudes. The punctum proximum, defined by the electric monocular proximometer and verified by refractometry, approaches the eye in direct relation with the

altitude, being a function of the training of the pilot for high-altitude flights.

Checking on the visual accommodation, by direct studies of the near point in



Fig.10 - Ciliary Body, Presenting Ectactic
Vessels with a Slightly Thickened Wall

the altitude chamber during the test, has established that the instant of its
approximation to the eye occurs about 15 minutes after start of the altitude-

chamber test and then diminishes progressively until the end of the test. Return to normal at sea level, at rest, takes place 25 - 45 min after leaving the



Fig.11 - Zonule of Zinn, Presenting a Tendency of the Constituent Fibrils to Condense

altitude chamber.

Experimentally, it was found that the rapid drop in atmospheric pressure

causes the appearance of gases dissolved in the retro-ocular adipose tissue, meaning that the volume increases proportionally with the altitude, resulting



Fig.12 - Condensation of the Fibrils of the Zonule of Zinn, Presenting a Plicate Aspect at the Level of their Insertion into the Crystalline Lens

in a diffused gaseous infiltration of the orbital cellular tissue - orbital emphysema - with consecutive protrusion of the eye and a crepitant sensation

when slight pressure is exerted on the ocular globe. These gases, expanded at the level of the orbital adipose tissue and having a modified partial pressure, interfere with the nerve conduction and with the repolarization at the level of the ciliary ganglion, which is the most important station for all sympathetic and parasympathetic nervous fibrils which lead to the formations of the accommodative system and to the entire ocular globe.

If the ascents are rapid, the gases dissolved in the humors change from the soluble form into the gaseous state and lead to gaseous emboli. In the appearance of such emboli, nitrogen plays the main role since it is chemically linked to the organism, possesses a reduced diffusibility, and represents 70% of the atmosphere. When dissolved in fats, i.e., also in myelin, nitrogen produces perturbations on the nerve tracks; under the form of microemboli, nitrogen distends the nerve sheaths, leading to disorders in conductivity. Experimentally, in our histopathological studies made at reduced pressure, we found lesions of an infiltrative edematous aspect, hyperemia, hemorrhages, and modifications in the vascular walls, intensifying the reversible functional disorders which appear at the level of the visual analyzer of pilots under conditions of slight hypoxia to maximum intensity, compared to the experimental values. p.7

In all the cases studied from a histopathological viewpoint, we found a distinct hyperemia at the level of the ciliary body, a descent of the ciliary process toward the aequator lentis; the confluent fibrils of the zonule of Zinn were thickened and relaxed, inserted into a greatly bulging crystalline lens.

This histopathological picture explains the state of accommodative spasm of the ciliary muscle produced under the negative pressure of great altitudes, which we also encountered during altitude-chamber tests, studied from an evolu-

...tive and dynamic viewpoint by means of the electric monocular proximometer.

The low-pressure myopia extended over a period of 25 - 45 min after leaving the altitude chamber and was directly proportional to the degree of reduced pressure at altitudes above 5000 m, in subjects trained for flight at great altitudes. The low-pressure myopia being directly proportional to the degree of negative pressure (above 5000 m) only emphasizes the stability of the phenomenon of ciliary spasm under the influence of altitude. The duration of low-pressure myopia is in direct relation with the training for high-altitude flights, clearly demonstrating the promptness of adaptation of the ciliary muscle which probably by then has hypertrophied due to the numerous effects of repeated pressure reductions.

The hypobaric myopia is complicated by a hypoxic myopia resulting in occupational myopia of pilots. Apparently, no parallelism exists between the obtained results: Whereas the accommodation of the punctum remotum is normal, that of the punctum proximum indicates a state of myopia. However, this fact is merely apparent since the distant sight is normal while only the sight between the punctum remotum and the punctum proximum is influenced by the myopia occurring during the period of reduced pressure. This hypobaric altitude myopia becomes more pronounced the more the sight approximates the punctum proximum. In view of the fact that the recordings of the phenomenon were made during the altitude-chamber tests, i.e., in an evolutive dynamic manner, one cannot speak of an inverse phenomenon which could have been produced by a decompensation or desaccommodation, because the normalization of the phenomenon takes place slowly after the end of the test, in proportion with the altitude. The hypobaric myopia is produced by the spasm of the ciliary muscle under the influence of hypoxia, i.e., of the chemical component and of the partial pres-

sure of the gases (physical component) which becomes modified and interferes with the functioning of the peripheric nervous system, at the level of the optic tracts and of the cortex. A statistical analysis of the data obtained by proximometry and refractometry in the four groups of pilots shows an evolution of the ocular refraction up to hypobaric myopia, which is relatively high ($p < 0.001$) with respect to the state of rest. Because of the appearance of this hypobaric myopia, it is recommended in selecting the pilots, to choose those that exhibit a slightly hypermetropic (+1, +2 diopters) or emetropic (normal) type of ocular refraction. Pilots with myopia which might become worse under the effect of reduced pressure, should be rejected. A.A.Volohov and L.C.Zagorulko (see Bibl.14) demonstrated that the visual acuity changes only slightly at a moderate oxygen deficiency (at altitudes of 4000 - 5000 m) but becomes considerably less at high altitudes. The hypoxic states exert a greater influence on the visual acuity in persons with refraction anomalies, specifically in the case of astigmatism (I.M.Heller, cited in Bibl.14). Consequently, the selection of pilots from the viewpoint of the type of ocular refraction is of great importance for flights at high altitudes which require a normal emetropic refraction or even a slight hypermetropia of +1 to +2 diopters. All persons suffering from myopia, astigmatism, or anisometropia should be rejected even if the differences are minimal (0.5 diopters). All optical ametropias, including the occupational low-pressure myopia, will lead to fatigue symptoms because of the considerable strain exerted on the visual analyzer during flight.

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Work conducted at the Faculty of
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REFERENCES

1. Benetato Gr., Baciuc I., Oprean R., Telia N., Comunic.Acad.RPR 1956,
Vol.6, No.1, p.152
2. Benetato Gr., Fiziol.norm.si patol., 1961, Vol.7, No.2, p.107
3. Carapancea M., Popescu M., Pintilie I., Stoian M., Teodorescu V.,
Stefan M., Stud.si cercet.fiziol., 1961, Vol.6, No.1, p.129.
4. Carapancea M., Popescu M., Ratiu E., Pintilie I., Stoian M.,
Stefan M., Stud.si cercet.fiziol., 1961, Vol.6, No.3, p.511.
5. Carapancea M., Popescu M., Stefan M., Bengulescu D., Musetescu
St., Stud.si cercet.fiziol., 1961, Vol.6, No.4, p.695.
6. Erdbrink W.L., Aerospace Medicine 1963, Vol.34, No.8, p.762.
7. Grascenko N.I., Vopr.fiziol., 1959, No.6, p.88
8. Green I.D., Aerospace Medicine, 1961, Vol.32, No.5, p.407
9. Mercier A., Robert A., Congr.Mondial de Med.Aeron.III-e Congres
Europeen, Louvain 1958, p.185.
10. Mercier A., Ann.d'Oc., 1960, Vol.193, No.2, p.138.
11. Mercier A., Ann.d'Oc., 1962, Vol.195, No.1, p.53.
12. Perdriel G., Revue des Corps de Sante des Armees, 1963, Vol.4, No.5, p.601.
13. Platonov K., Omul in zbor, Ed. Milit.a Fort.Arm.RPR, Buc.1959.
14. Popov A.P., Medicina Aeronautica, Ed.Milit.a Fort.Arm.RPR, Buc., 1961.
15. Popescu M., Fiziol.norm.si patol., 1963, Vol.9, No.6, p.563.
16. - Fiziol.norm.si patol., 1963, Vol.9, No.1, p.67.
17. - Stud.si cercet.fiziol., 1963, Vol.8, No.2, p.375
18. Popescu M., Stefan M., Cincu N., Pintilie I., Stud.si cercet.
fiziol., 1964, Vol.8, No.3.
19. Whittington T.H., The art of clinical refraction, Ed.Oxford Medical
Publications - London 1958, p.11